Modulation of Predatory Strike Speed Based on Prey Speed in Mantis Shrimp (*Coronis Scolopendra)*

Ilin Joshi, Kathryn Feller, Paloma Gonzalez-Bellido

Department of Evolution, Ecology, and Behavior

University of Minnesota

Introduction

Mantis shrimp are crustaceans of the order Stomatopoda, which are known for their elaborate vision and fast predatory strikes. All mantis shrimp utilize a pair of raptorial striking appendages for both predation and defense . The strike is accomplished using a spring-actuate, latch-mediated mechanical mechanism, , similar to a crossbow, which allows incredible striking speeds of up to 30m/s (Cox et al, 2014). In addition, the eyes of the mantis shrimp are among the most complex in the entire animal kingdom, being able to detect light ranging from far-red to deep ultraviolet, as well as polarized light, an ability most vertebrates lack (Cronin et al, 2014). This combination of vision and ultra-fast striking make mantis shrimp a valuable neuroscience system to investigate the neural and physiological mechanisms that control this predicted behavior. The goal of this experiment, then, was to test the mantis shrimp's ability to modulate the speed of their strikes relative to the speed of their strike targets. We hypothesized that, when presented with artificial prey stimuli, the shrimp will strike faster to catch faster-moving prey, striking slower for slower prey.

Methods

All data were collected from male mantis shrimp of the species *Coronis Scolopendra*, as females were less receptive to the prey stimulus. Spearing mantis shrimp of this type create burrows in the sand to ambush prey, rising out and striking if they see it (DeVries et al, 2012). The stimulus was composed of a small glass bead, tied to NanoFil 0.0357 mm nylon string. The string was then attached to a transparent glass rod using tape or waterproof putty. The stimulus was presented to the shrimp in its natural burrow, built in an aquarium in the lab, using one of two methods. In the first method, the stimulus was passed over the shrimp's burrow by hand, and in the second method, it was attached to a linear slider robot that moved the stimulus over the burrow at a set speed. The robot method provided the most reliable stimulus speed and direction, however hand-controlled stimuli needed to be used in situations where the robotic arm would not fit (as in the case of shrimp M2, who made his burrow in the corner of the tank).

Strikes were recorded at 5000 fps using a high-speed video camera (Photron Fastcam). From the raw video recording of a strike, two video files were saved: one recording the motion of the bead before the strike (whose frame rate was downsampled to 50 fps for analysis), and one recording the strike action itself. After the frame rate of the bead videos had been reduced, the average speed of the bead was approximated by finding the average speed of the portion of the video just before the strike using ImageJ.

The videos showing the strike action were divided into two categories: lateral view and nonlateral view. Nonlateral view refers to videos where the shrimp was somewhat or fully facing forward or back relative to the camera, so the exact rotation velocities could not be calculated. For these videos, the total strike time was calculated using the frame data for the start and end of the strike. For the videos with a lateral view (where the shrimp was looking to the side), the same process was conducted to find the strike time, but a more advanced analysis was done as well. Using ImageJ, the strike was tracked with the plugin mtrackJ, against set reference points on the animal. Then, the peak angular velocity and acceleration were calculated from these track data using R. In total, there were 57 strikes analyzed, 23 of which were of a good enough angle to calculate the peak angular velocity and acceleration.

Data and Analysis

There was a total of three shrimp whose strikes were analyzed: M1, M2, and M3 (the M standing for “male”) The strike times of all 57 strikes were compared to the speeds of the bead in the video, shown below in Figure 1.

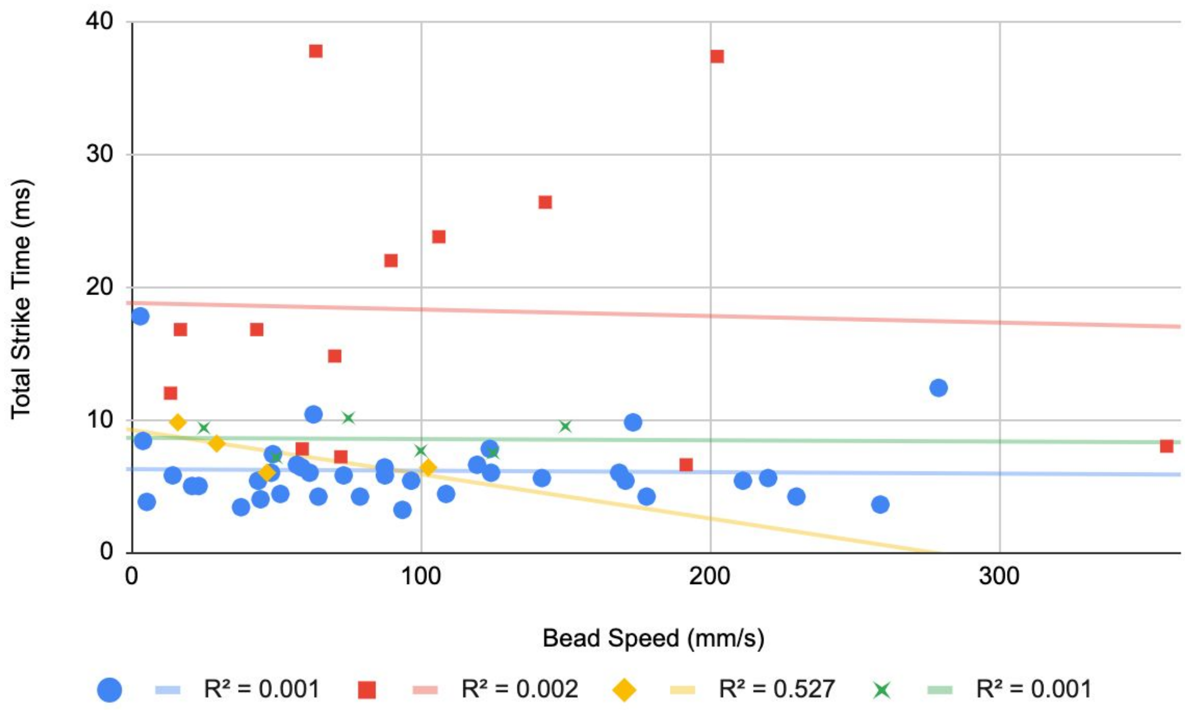

Figure 1: Total time of mantis shrimp strikes relative to speed of the prey stimulus moving over the animal’s burrow. The blue circles represent strikes by shrimp M1, the red squares represent strikes by shrimp M2, and the yellow diamonds represent strikes by shrimp M3. The green X marks show the average strike time for a set of 25 mm/s of bead speed below the X mark, i.e 0-25, 25-50, etc. The final green X is the average for all points with a bead speed above 150 mm/s.

Most of the strikes took approximately the same time, being between 5 and 10 milliseconds, particularly for M1's strikes. In contrast, M2 was responsible for all of the various outliers, all of which were slower than the average. For M1 and M2 there was no correlation between the strike time and the speed of the stimulus ($R^2 \leq 0.002$). M3's strikes showed a negative correlation, decreasing in speed as the speed of the stimulus increased ($R^2 = 0.527$). Overall, using the average data, there was no correlation ($R^2 = 0.001$)

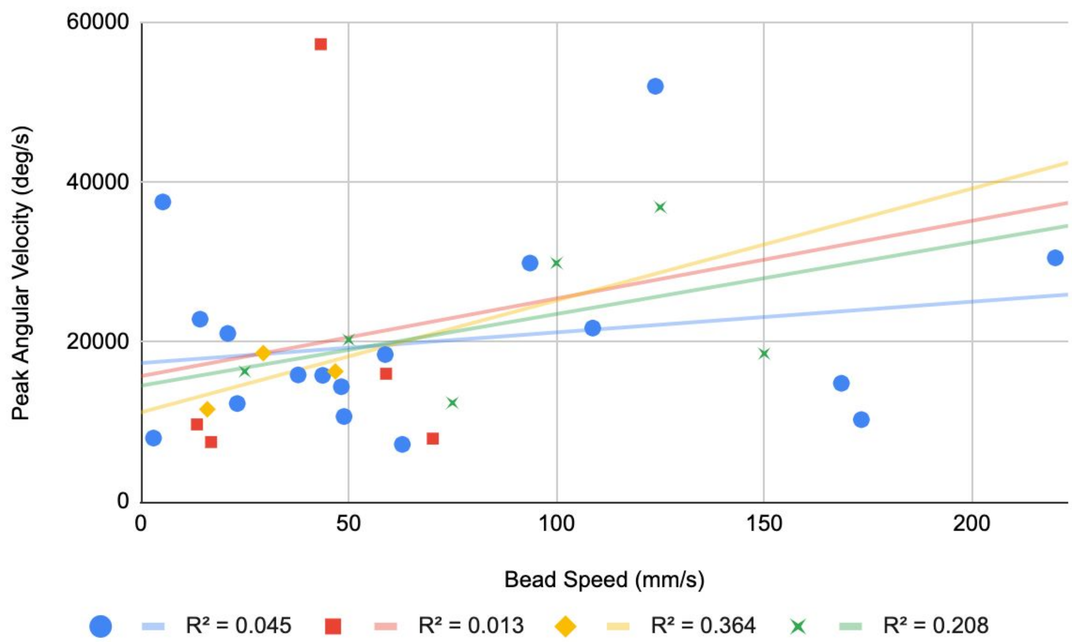

Figure 2: Maximum angular velocity of mantis shrimp strikes relative to speed of the prey stimulus moving over the animal's burrow. The blue circles represent strikes by shrimp M1, the red squares represent strikes by shrimp M2, and the yellow diamonds represent strikes by shrimp M3. The green X marks show the average strike time for a set of 25 mm/s of bead speed below the X mark, i.e 0-25, 25-50, etc. The final green X is the average for all points with a bead speed above 150 mm/s.

For the section of strikes which were given the more extensive analysis of maximum velocity and acceleration, the results followed that of the total strike time. The peak velocity of the strikes are shown in Figure 2 relative to the speed of the stimulus. In general, the peak velocity had a greater correlation with bead speed than total strike time. M1 showed a weak positive correlation (R^2 = 0.045) and M3 showed a stronger correlation (R^2 = 0.364). M2 showed a very weak positive correlation (R^2 = 0.013), but an outlier with a very high speed likely confounds the results for this shrimp specifically. On average, the peak velocity has a positive correlation with total strike time (R^2 = 0.208). Most of the peak velocities fell within a relatively small range of values; the interquartile range of the velocities fell between 10496.85 and 22314.5 deg/s.

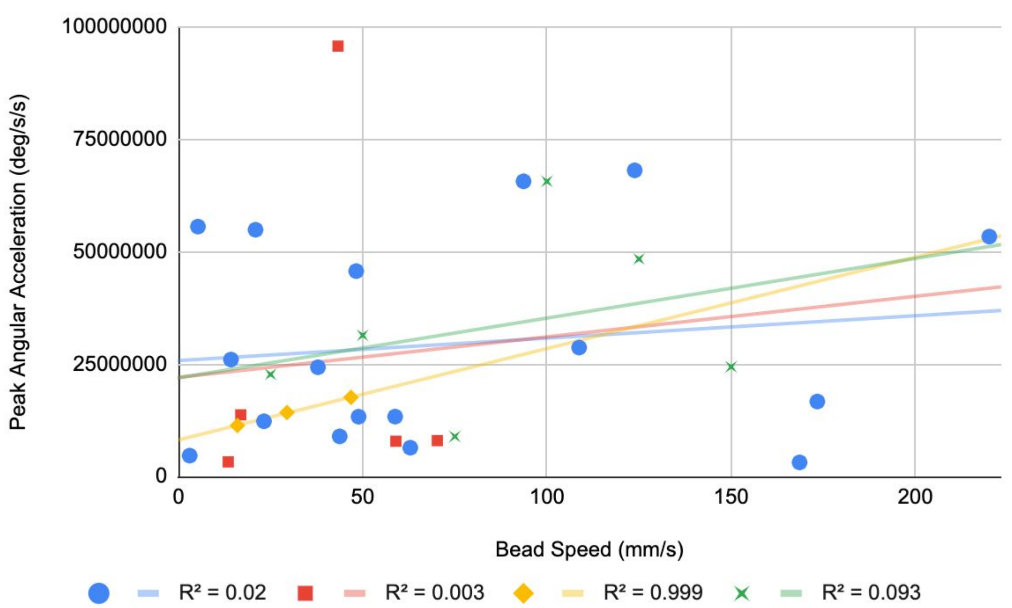

Figure 3: Maximum angular velocity of mantis shrimp strikes relative to speed of the prey stimulus moving over the animal's burrow. The blue circles represent strikes by shrimp M1, the red squares represent strikes by shrimp M2, and the yellow diamonds represent strikes by shrimp M3. The green X marks show the average strike time for a set of 25 mm/s of bead speed below the X mark,

i.e 0-25, 25-50, etc. The final green X is the average for all points with a bead speed above 150 mm/s.

The maximum acceleration had a similar trend of increasing as the stimulus speed increased, though again with a weak correlation on average (R^2= 0.093). M1 had a weak correlation (R^2 = 0.02), and M3 had very high correlation (R^2 = 0.999). As with the peak velocity, an outlier with very high acceleration greatly affected the trendline and correlation for M2. Unlike the peak velocity, the values for the peak acceleration did not mostly fall within a given range of values, but had great variation.

An additional variable was also measured in each video: the distance from the animal to the stimulus when it has noticed the stimulus and decided to strike (seen by the animal's eyes and antennae locking onto the target). The peak velocity of the strikes showed a greater positive correlation to this distance than to the speed of the stimulus itself, shown on the following page in Figure 4. This correlation was not matched by the total strike time, which again showed little to no correlation.

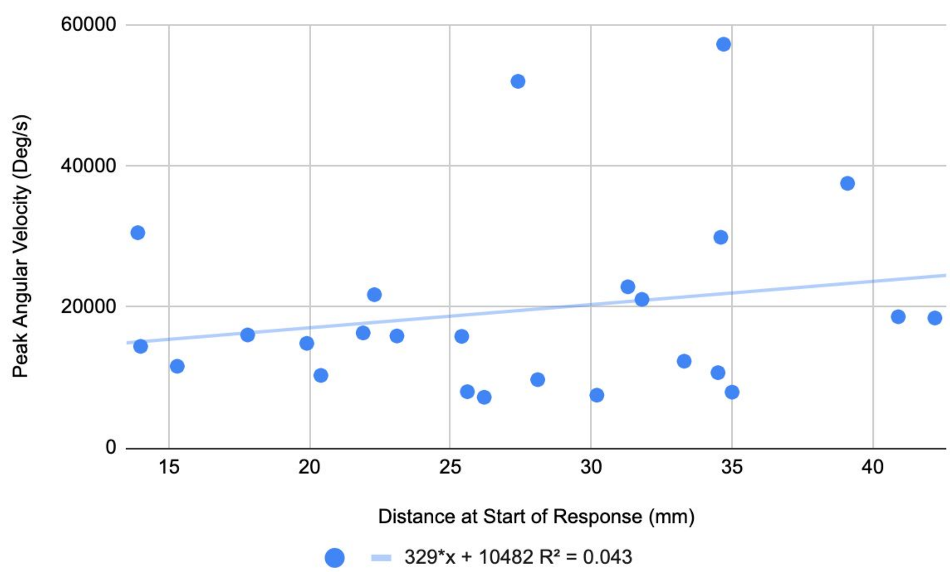

Figure 4: Peak angular velocity relative to the distance from the animal to the bead at time of response (combined data for all three shrimp). Time of response here is defined as the moment the animal's eyes and antennae lock onto the bead in preparation to leave its burrow and strike. Any moments of locking on without striking were ignored.

Fatigue among the shrimp was a factor that was not initially considered, yet might have contributed to any possible errors in the data. In shrimp M1, from which most of the data was collected, possible fatigue was measured, shown in Figure 5.

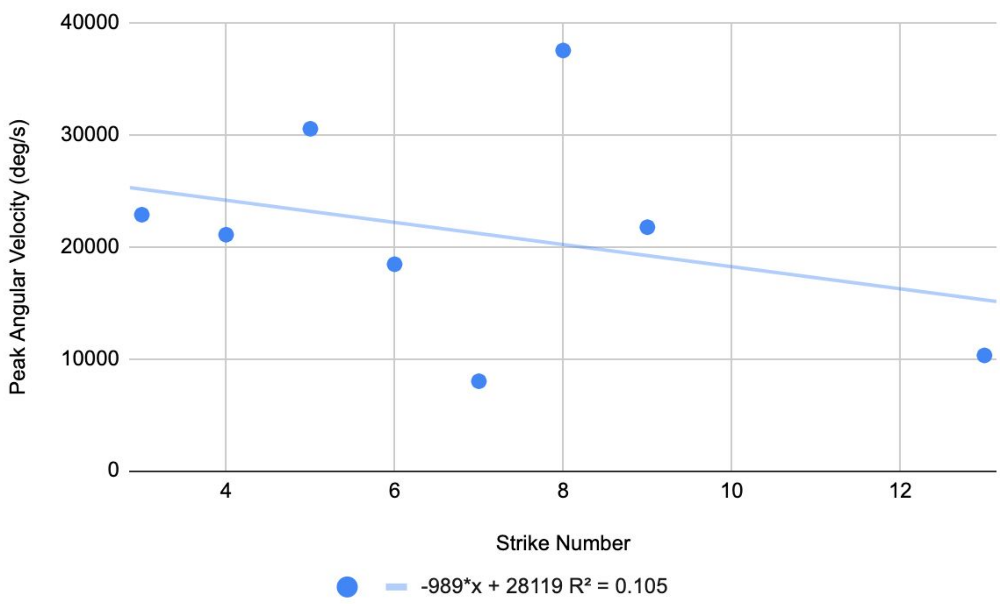

Figure 5: Fatigue in shrimp M1. The strike number refers to the order of the strikes over the course of the testing period.

All of the data in Figure 5 was collected from a single recording session, about 3-4 hours. The slowing of the strikes over this time are most likely due to fatigue from overuse of the striking mechanism.

<u>Discussion</u>

While there is correlation between strike speed and prey speed, overall, these data do not provide strong support for our hypothesis that the mantis shrimp modulate the speed of their strike in response to the speed of their prey. Indeed, the data show that the strikes may be more stereotyped, as most of the peak velocities and total strike times (which represent the average velocities) fell within a given range of values. Despite this lack of variation, a surprising result was the weak correlation of peak strike velocity with the distance from the animal to the stimulus. If this is indicative of a genuine trend, it could signify that any modulation of speed carried out by the shrimp could have to do with the distance to the prey just as much as the prey's speed However, given the weak correlation, this hypothesis would require further investigation to determine a more satisfactory result.

One element of the experiment which may have affected the results was the number of shrimp available. At the start, there were two male shrimp and two female shrimp. However, the females of this species showed little desire to hunt, and so were uncooperative as they rarely struck with the frequency of the males. Later in the semester, a second batch of individuals were acquired from Florida: three females and three males. One of the males was able to sufficiently acclimate to the lab prior to the end of the UROP research term, raising our n-value to 3 participants. Females continued to not strike from their burrow, despite displaying active foraging behaviors. The majority of our data were collected from one individual, M1. Due to the potential effects of fatigue or variation in individual behavior (personality), data from this single shrimp are likely insufficient to represent the behavior of the entire species.

These results, though inconclusive, provide a basis for further investigation into the factors potentially influencing mantis shrimp strike speed modulation, a behavioral phenomenon presently known to occur between behavioral tasks (such as fighting vs. foraging, Green et al 2019) though poorly understood within a single behavioral paradigm. The greater correlation of speed and distance to prey than speed and prey speed call for further and more focused investigation into whether or not the shrimp use distance to determine their striking speed. Future work based on this study could also examine other results of this study in more detail, such as the sexual dimorphism of the shrimp's behavior, or the fatigue induced from overuse of the striking appendages. Finally, if the mantis shrimp have control over their striking speed, an experiment could be used to find the neurophysiological mechanisms of the strike, to determine how the shrimp maintain control over such a fast-moving and powerful appendage.

References

- Cox, S.M., et al. "A physical model of the extreme mantis shrimp strike: kinematics and cavitation of Ninjabot." *Bioinspir. Biomim* 16014, 2014, pp. 1-16
- Cronin, T. W., et al. "Filtering and Polychromatic Vision in Mantis Shrimps: Themes in Visible and Ultraviolet Vision." *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 369, no. 1636, 2014, pp. 20130032–20130032.
- DeVries, M.S., et al. "Strike mechanics of an ambush predator: the spearing mantis shrimp." *Journal of Experimental Biology* 215, 2012, pp. 4374-4384
- Green, P.A., et al. "Context-dependent scaling of kinematics and energetics during contests and feeding in mantis shrimp." *Journal of Experimental Biology* 222, 2019